AN INTERNATIONAL PLANT SENTINEL NETWORK

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ABSTRACT

Invasive plant pests and pathogens pose a major threat to biodiversity around the world, amplified in recent years by the globalisation of trade in plants and plant material and the impacts of climate change. Botanic gardens and arboreta offer a unique opportunity for the identification and further investigation of new and emerging pest and pathogen risks, which can provide valuable information for the creation of prevention, eradication and control programmes. The International Plant Sentinel Network (IPSN) is being developed to provide a platform for coordination, information exchange and support for sentinel plant research within botanic gardens and arboreta. Alongside IPSN Member Gardens, the network includes plant protection professionals and National Plant Protection Organisations (NPPOs) from around the world. The IPSN provides tools which will help to enable gardens to contribute to research by increasing knowledge and awareness among garden staff, developing standardised approaches and providing training materials and methodologies for monitoring and surveying. The network also promotes links with local professional diagnostic support that can help aid the early detection and rapid response to new pest incursions, thus protecting valuable, and often unique, plant collections.

INTRODUCTION

Invasive plant pests and pathogens pose one of the greatest threats to biodiversity and ecosystem health worldwide; outbreaks have had, and will continue to bear, serious economic and environmental consequences (Aukema *et al*., 2011; Tomoshevich *et al*., 2013). These organisms can have a devastating impact on local flora due to a lack of natural enemies, which would ordinarily control numbers, and a lack of evolved resistance by their new hosts (Tomoshevich *et al*., 2013). A significant issue in protecting countries from such invasive species is that the majority of the most damaging organisms introduced into temperate forests in recent years are not considered pests in their native regions (Kenis *et al*., 2011). For example, the emerald ash borer (*Agrilus planipennis*, Fig. 1a and b) entered North America in 2002 and within 5 years killed over 53 million native ash, *Fraxinus* spp. (Kramer, 2010). However, it is native to countries in Asia,

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including Japan, Russia and China, where it is merely considered a secondary pest which attacks stressed or dying ash trees (Poland & McCullough, 2006; Straw *et al*., 2013).

Preventing the introduction and subsequent establishment of a pest is the most cost-effective management tool that plant health policy-makers and scientists have available to them (MacLeod *et al.*, 2002). Thus understanding the risks of when and where

Fig. 1 Emerald ash borer, *Agrilus planipennis.* Photo: UK Crown Copyright – courtesy of FERA.

Fig. 2 Emerald ash borer damage. Photo: Michael Bohne, Bugwood.org.

an organism could be a significant threat to plant health is vital. Similarly, generally increasing our knowledge about known pests and pathogens will aid in the creation of successful management practices, often referred to as Integrated Pest Management (IPM). Developing correct and robust host lists for damaging organisms also focuses monitoring efforts, increasing the chance of detection, and allows the identification of those species and areas most at risk within a country.

THE INTERNATIONAL PLANT SENTINEL NETWORK

The International Plant Sentinel Network (IPSN) is being developed to provide an early warning system for new and emerging pest and pathogen risks. Botanic gardens and arboreta that join the network will monitor species within their living plant collections in order to provide information relevant to plant health. The Network will provide a platform for coordination and communication regarding plant health, as well as offering training and surveying materials in order to increase capacity for such work among staff. In this context 'Sentinel' refers to the presence of exotic plant species growing outside their natural ranges (for example in botanic gardens and arboreta) that can be monitored to provide information regarding pests and pathogens. IPSN Member Gardens will work closely with local National Plant Protection Organisations (NPPOs) and plant protection scientists to identify potential new threats and investigate any organisms causing damage.

The IPSN is part of a EUPHRESCO project (EUropean PHytosanitary RESearch COordination), Phytosanitary ERA-Net. The aim of EUPHRESCO is to tackle the steady rise in the introduction and establishment of plant pests and pathogens and the declining capacity for phytosanitary science across Europe (EUPHRESCO, 2015). In the UK the IPSN is funded by the Department for Environment, Food and Rural Affairs (DEFRA) and is led by Fera. Fera is an executive agency of DEFRA whose Plant Health Team includes leading experts in the field of plant pest and pathogen identification. In recent years Fera has become heavily involved in plant health citizen science projects in the UK, including Open Air Laboratories (OPAL) Tree Health Survey (OPAL, 2012) and ObservaTree. Fera further subcontracts to Botanic Gardens Conservation International (BGCI), which coordinates the development of the network as well as CABI[5] (UK) and Forest Research (UK). Other EUPHRESCO partners are the Julius Kühn-Institut (Germany), the Plant Protection Services (Netherlands) and the Department for Innovation in Biological, Agro-food and Forest Systems (Italy). Partners can, and are welcome to, join at any time during the lifetime of the project. Despite being a European-funded project, the aim of the IPSN is to create a truly global network of botanic gardens, arboreta, plant health institutes which offer diagnostic services and National Plant Protection Organisations.

5. CABI is a non-profit international organisation which provides information and scientific expertise to solve agricultural and environmental problems to help improve people's lives.

BGCI: GardenSearch and PlantSearch

The coordination of the project is being undertaken by BGCI, a plant conservation charity which provides support for botanic gardens and arboreta worldwide. As well as providing key links to gardens around the world and experience in managing similar networks, BGCI also has two databases, GardenSearch and PlantSearch, which provide key support to the development and activities of the IPSN. GardenSearch includes profiles on nearly 3,250 botanic gardens worldwide which provide their location, information on collections and contact information (GardenSearch, 2015) (Fig. 5). PlantSearch is the only global database of living plant collections, containing more than one million collection records (PlantSearch, 2015). The two databases offer a unique opportunity to identify appropriate collaborators from around the world; PlantSearch is particularly useful as it allows for the identification of gardens that have particular species of interest within their collections.

MANAGING THE THREAT

The threat from invasive plant pests and pathogens is ever increasing, due to continued globalisation and rising pressures from climate change (Miller *et al*., 2009; Liebhold *et al.*, 2012; Tomoshevich *et al*., 2013). The annual rates of invertebrate, plant and mammal introductions have all risen steadily since the year 1800, coinciding with the rise in international trade as a result of the industrial revolution. Furthermore, this trend shows no sign of abating; within Europe the highest rates of invasions ever recorded were observed in the last 25 years (Hulme, 2009). A major pathway for the arrival of invasive plant pests and pathogens is via traded plants and plant material (Liebhold *et al.*, 2012). For this reason nursery stock is a common pathway for introductions, yet in the USA it is estimated that only 2 per cent of nursery stock shipments are inspected, a trend seen worldwide (Britton, 2010; Britton *et al.*, 2010).

It is the responsibility of a government, through the appropriate NPPO, to protect natural plant systems against invasive organisms, while at the same time stopping their own native species from becoming invasive (Miller *et al*., 2009). Pest Risk Analysis, or Assessment (PRA), is considered to be a key tool in mitigating the risk of invasive species. The technique uses biological, scientific and economic evidence on a pest or pathogen to determine whether an organism should be regulated or not and provides the technical justification for any phytosanitary measures imposed, such as inclusion in quarantine lists (Baker *et al*., 2009; Tomoshevich *et al.*, 2013). In Europe PRA is essential for preventing the entry and establishment of organisms deemed high risk to a country's plant health through trade (Baker *et al*., 2009). A major issue of PRA is that it relies on prior awareness and knowledge of a pest which is not always available (Kenis *et al*., 2011).

Quarantine lists are made up of organisms deemed to be a significant threat to plant health. These are subsequently regulated with the aim of preventing their introduction or

establishment. However, not all 'hitchhikers' on traded goods will become an invasive pest in a country, due to a lack of suitable hosts or climate. Ensuring that these lists are robust and correct is vital to plant health activities in order to target efforts and be efficient with government, importer and exporter resources. Identifying the damaging organisms and providing supporting evidence is vital for the creation of such quarantine lists.

THE UNITED KINGDOM AS A CASE STUDY

The outbreak of the fungus *Hymenoscyphus fraxineus* caused DEFRA to set up a 'Tree Health and Plant Biosecurity Expert Taskforce'. Otherwise known as ash dieback, named after the asexual stage of the fungus *Chalara fraxinea*, the fungus causes leaf loss, crown dieback and ultimately (more often than not) death of the affected tree. An assessment into the potential impact of this fungus in the UK found that ash made up 5.4 per cent of all tree species with a commercial value of £22 million, and that the fungus could cost a total of £17.3–£38.2 million per year in terms of lost social and environmental benefits (DEFRA, 2013a). The full effects of the ash dieback outbreak are yet to be revealed; however it has demonstrated the need for better protection against the introduction of such damaging organisms. The expert taskforce was set up with the sole purpose of providing advice on the risk from pests and pathogens with recommendations on how to prevent the introduction of threats. A major recommendation of the final report was to ensure that the UK was better prepared in understanding future threats to aid interception, contamination or control efforts. The report specifically mentions the use of sentinel plants, both within the country and abroad, to aid in the identification of unknown risks (DEFRA, 2013b).

The importance of predicting future threats, often termed 'horizon scanning', is evidenced by the recent outbreak and subsequent eradication programme in the UK of the Asian longhorn beetle (*Anoplophora glabripennis*, Fig. 2a). This longhorn beetle is a devastating pest of broadleaf trees (Fig. 2b) and poses a serious threat to species around the world (Straw *et al*., 2014). This is mainly due to its large host range and because it attacks healthy trees. Although actually native to China, the species has caused large-scale mortality of *Populus* species there since the 1980s, accruing an estimated loss of approximately $1.5 billion (10 billion yuan) per year (Hu *et al*., 2009). In 2012, a finding of the immature stage of the beetle was confirmed in Paddock Wood, Kent, UK. The resulting eradication programme included felling 2,229 trees, the creation of buffer zones (100–800 m from infested trees), communication with the public and media, and continued surveillance. Although the site will be monitored until 2016, and the pest cannot be designated eradicated until then, no signs of the beetle have been discovered since 2012 (Dixon, 2013; Straw *et al*., 2014). The identification of the Asian longhorn beetle as a significant threat to the UK before its introduction led to quick identification and subsequent action. Inevitably, this was pivotal to the success of the management programme imposed.

Fig. 3 Asian longhorn beetle, *Anoplophora glabripennis*. Photo: UK Crown Copyright, courtesy of Fera.

Fig. 4 Damage by *A. glabripennis* on poplar trees in Ningxia, China. Photo: Michael Bohne, Bugwood.org.

SENTINEL PLANTS

When plants are maintained outside of their natural ranges they can act as standing sentinels for their species, offering a unique opportunity to understand and predict potential threats. These sentinels can be monitored for damage by organisms which are found naturally in the new 'hosting', or surrogate, region but are non-native to the species' country of origin. Any significant threats identified can then be reported to the country in which the species naturally occurs. This information can then be used to provide an early warning for potential future threats and can help to focus efforts and aid plant protection efforts at a regulatory level, for example within PRAs.

Sentinel research

The idea of using sentinel plants to provide information on new and emerging pests and pathogens is not a new concept. There have been a number of recent leading programmes that have used, and some are still using, sentinel plants to fuel research:

- The New Zealand Expatriate Plant Programme focused on monitoring endemic New Zealand species existing in living collections around the world. Run by the Better Border Biosecurity (B3) Consortium, the programme used climate matching to locate suitable gardens with New Zealand natives. New Zealand specialists would then go to the identified gardens in order to survey individuals using standardised forms designed for various different types of pathogen – insect, nematode, etc. The programme ran for five years, in which time it identified a total of ten previously unknown pest-host associations (Fagan *et al*., 2008; Britton *et al*., 2010).
- PRATIQUE (Enhancements of Pest Risk Analysis Techniques), like the IPSN, was a EUPHRESCO project that investigated the use of sentinel research to aid PRA activities. Two sentinel plots were established in China which involved planting five different species of European tree. Results yielded large numbers of colonising insects, five of which were identified as significant risks to European plant health and proposals for PRAs. However high levels of mortality were observed among seedlings which may have resulted from adverse climatic conditions or quarantine conditions where they had to be stored for three weeks upon importation (Kenis *et al*., 2011). Another element of PRATIQUE included surveying European and Eurasian tree species in Russia. The study was highly successful, with results from the Siberian gardens alone resulting in the discovery of 29 pest-host associations previously unknown to science (Tomoshevich *et al*., 2013). Kenis *et al*. (2011) recommended the creation of a global network of botanic gardens as a way of continuing this work. Another outcome of the project was the revision of the decision-support scheme (DSS) for carrying out PRAS under the European and Mediterranean Plant Protection Organisation (EPPO) (Baker *et al*., 2009). These

revisions increased user-friendliness, consistency and transparency for the process (Steffen *et al*., 2012).

- ISEFOR (Increasing Sustainability of European FORests) is another EUPHRESCO collaborative project aimed at finding ways to detect invasive plant pests and pathogens within their most common dispersal and introduction pathway; live plants transported for planting out. ISEFOR is working on technologies to diagnose problems and predict future invasions (ISEFOR, 2015). The project has been set up and is currently monitoring sentinel nurseries in China of Chinese plants which are regularly traded with countries from within the European Union. This approach aims to identify organisms that could potentially be brought into Europe through trade with China, whilst at the same time bypassing issues seen in PRATIQUE around climatic suitability and importing European species.
- Funded by the United States Department of Agriculture – Animal Plant Health Inspection Services (USDA-APHIS) the Sentinel Plant Network (SPN) provides training and outreach to American botanic gardens and arboreta. The project is a collaboration between the American Public Gardens Association (APGA) and the National Plant Diagnostic Network (NPDN). The SPN provides training workshops and educational outreach materials, and extends the existing NPDN 'First Detector' programme which provides diagnostic training and public outreach to over 500 APGA Member Gardens already. The overall aim is to increase monitoring activities, speed up first detection and provide outreach to the public (Britton *et al*., 2010; Sentinel Plant Network, 2015).

The IPSN has spent the last year learning from the projects described above, and members of all of these projects are fully informed and involved in IPSN. The aim is to ensure that the project builds on the existing knowledge and experience that already exists.

AN INTERNATIONAL NETWORK OF BOTANIC GARDENS AND ARBORETA

The spread and subsequent establishment of invasive pests and pathogens is a global problem, and should be tackled as such. Recent papers have strongly recommended that a global network of arboreta and botanic gardens working with plant protection institutes could provide warning of new and emerging threats (Britton *et al*., 2010; Kramer, 2010; Tomoshevich *et al*., 2013). Further to this a 2011 survey of botanic gardens and arboreta revealed that these institutes have the resources and expertise to help, but that they are lacking support and coordination which would help to expand existing efforts (Kramer & Hird, 2011).

The advantages of using botanic gardens and arboreta to create a sentinel network are abundant. Their living plant collections are valuable and unique scientific resources. It is estimated that 30–40 per cent of known plant species are grown in living collections of botanic gardens and arboreta throughout the world (Kramer, 2010; Kramer &

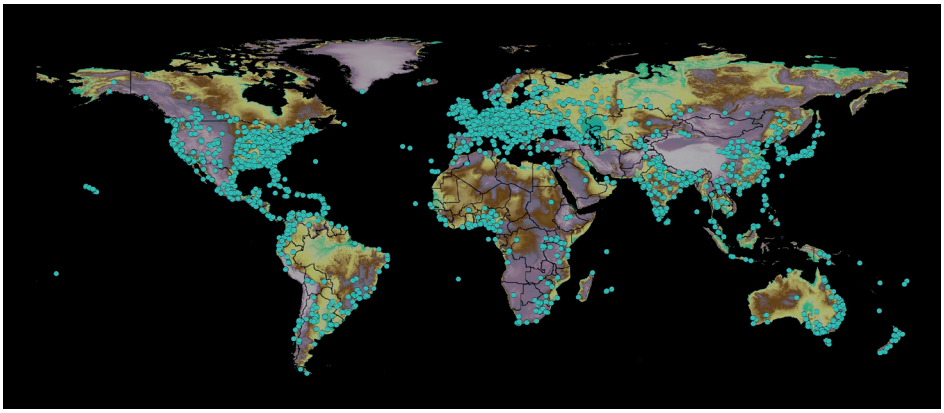

Fig. 5 Spread of botanic gardens and arboreta from BGCI database GardenSearch. Each green dot represents a botanic garden or arboretum which is a member of BGCI. Image reproduced from BGCI GardenSearch.

Hird, 2011; Fig. 3). International collections containing species from around the world, non-native to the region, country or even continent of the garden they are being hosted by, provide the perfect location for sentinel research. These expatriate plants can act as standing sentinels for potentially invasive pests and pathogens, helping us to understand and predict when and where plant species could be susceptible to pests. In addition, gardens hold records of the plants in their care which can provide important information to assist in the monitoring and recording process.

Another unique and key asset botanic gardens and arboreta have to offer is the expertise of their staff. Horticultural staff have a wealth of knowledge about the plants they work with, and this can aid in their understanding and prediction of what is causing particular symptoms. Further to this, due to their familiarity with collections, they are likely to be able to recognise any change in the health of a plant. Staff have an understanding of the plant and are able to access information through the records kept on the history of the plant including its origin, general health, management issues, surrounding environment, climate and recent weather conditions. This knowledge can provide key clues to the cause of any deterioration of health in a plant, potentially revealing or ruling out abiotic causes.

CASE STUDIES

The following are examples of different sentinel studies that are already being undertaken by various botanic gardens and arboreta around the world, and who are all part of the IPSN:

Red band needle blight

The Yorkshire Arboretum in the UK has been instrumental in the investigation of the defoliating disease red band needle blight (RBNB), caused by the fungus *Dothistroma septosporum*. An outbreak of the fungus within the garden has enabled further study of the problem. A student-led project (from Askham Bryan College) was set up in collaboration with the arboretum and Fera. The project investigated the efficacy of a field-diagnostic technique called the GENIE, used to detect the fungus (Fig. 4). The study provided a useful validation of the method's practical strengths and limitations.

Myrtle rust

Myrtle rust (*Puccinia psidii s.l.*) is a species of fungus that seriously damages its host; *Myrtaceous* species are particularly vulnerable and thus the fungus poses a real threat to many plants endemic to New Zealand. Consequently, since its first detection in Australia in 2010, New Zealand has been on high alert for any signs of the fungus. As discussed above, the quick detection and ability to manage any outbreaks is essential to the success of any eradication and containment programmes put in place to mitigate loss. Auckland Botanic Garden has established a project to monitor for the disease; a sentinel plot of *Myrtaceous* plants are regularly checked for any signs. The aim is to detect its presence in the country as early as possible, and to collect information on host preferences and rate of spread if it does arrive.

Azalea sawfly

The Charles University Garden in the Czech Republic has been instrumental in the discovery of and subsequent investigation into the non-native azalea sawfly, *Nematus lipovskyi*. As well as collecting samples for analysis (of adults and larvae), a preliminary monitoring programme has been set up within the Garden to increase knowledge about the sawfly's biology and life cycle. The Garden has been working in close collaboration with the State Phytosanitary Administration and the Entomological Department of the National Museum in Prague (Macek & Šípek, 2015).

ADVANTAGES FOR BOTANIC GARDENS AND ARBORETA TO JOIN THE IPSN

As stated above, the 2011 survey revealed a solid foundation of activities tackling the issue of invasive species but also a need for support (Kramer & Hird, 2011). The study identified a need for more formal coordination of efforts centring on training and increased communication regarding the issue. The IPSN aims to fulfil this role, providing tools to increase engagement, capacity and capability in the area of plant health.

The IPSN will provide a centralised platform for communication, dissemination of information and coordination of efforts surrounding plant pest and pathogen identi-

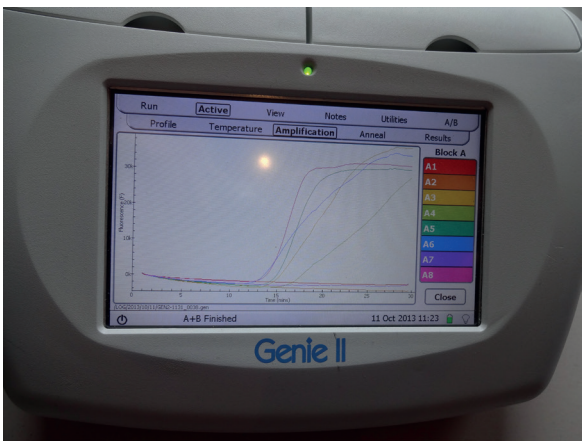

Fig. 6a (top) The GENIE being used in the field. Photo: Ellie Barham.
Fig. 6b (centre) Preparing samples at the Yorkshire Arboretum. Photo: Ellie Barham.
Fig. 6c (bottom) An example of the read-out obtained from the GENIE. Photo: Ellie Barham.

fication and management. The IPSN provides surveying tools and training materials which can be used by staff to increase their knowledge and awareness of this issue. Recently, the project has launched its own website which provides these key tools, links to relevant websites and further information on the project. In future this website will also become a platform for communication between participating gardens and plant protection scientists with fora in which issues can be raised and discussed.

Work will rely on botanic gardens and arboreta reaching out and working with their local plant health institutes. The IPSN will promote communication between institutes and, wherever possible, with local organisations which have the potential to facilitate collaboration on future research projects in the area and identify funding opportunities. Equally, this will ease access to diagnostic help of pests and pathogens; rapid response to an outbreak will inevitably help mitigate the level of damage sustained. Similarly, increasing staff awareness and understanding surrounding plant health issues will aid early detection, which, again, will help mitigate loss and potentially protect important plant collections.

The network offers an opportunity for botanic gardens and arboreta to showcase the scientific and research capabilities that their living collections have to offer. Gardens will be contributing on a global scale to the safeguarding of plant health.

PROGRESS AND FUTURE WORK

Since its launch in November 2013 at BGCI's 5th Global Botanic Garden Congress in Dunedin, New Zealand, the IPSN has been developing the network, working closely with botanic gardens, arboreta, plant protection scientists and NPPOs. Much of the work has focused on communication with relevant organisations and the general promotion of the network. As a result IPSN Member Gardens can now be found in Australia, Austria, China, Germany, Italy, South Africa and the UK. This work is ongoing and any garden is welcomed and encouraged to become an IPSN member regardless of size, location or expertise in the field of plant health.

A number of workshops have been held to build capacity and capability within gardens in specific regions:

- *China* – focused on longhorn beetles for Chinese and surrounding Southeast Asian gardens. It was hosted by Fairy Lakes Botanical Gardens, Shenzhen, which conducts research into longhorn beetles and thus has ample expertise in the subject.
- *USA* – hosted by the Huntington Library Art Collections and Botanical Gardens, this workshop was largely for staff members from Mexican botanic gardens. The workshop focused on two species of concern that have caused widespread damage in North America: the polyphagous shot hole borer, *Euwallacea spp.*, and the gold spotted oak borer, *Agrilus auroguttatus.*
- *UK* – hosted by Royal Botanic Gardens, Kew, this workshop sought to share

knowledge surrounding UK plant pests and pathogens and increase communication regarding issues and management.

Recent work has included the creation of a survey form, aimed at recording and monitoring change in unhealthy plants. Named the 'Plant Health Checker', as well as collecting information on plant health the form aims to increase the user's knowledge and awareness of plant pests and pathogens. Current IPSN Member Gardens have been pivotal in the creation of these forms, providing essential feedback and advice. Surveys will continue, with the aim of creating an electronic reporting system with a front-facing database in order to store and display data collected throughout the project, potentially supported by an app-based tool. The use of interactive web-based tools was another recommendation by the UK's Tree Health and Plant Biosecurity Expert Taskforce (DEFRA, 2013b) and will hopefully aid in creating a sustainable network. Further to this, it is hoped a number of tailored surveys will be created in order to provide information on certain 'known' pests and pathogens that require information to support PRAs.

As referenced above, there have been many projects that have preceded the IPSN. Consequently, as there is an opportunity to learn from these projects and ensure that the IPSN is not reinventing the wheel, the project has ensured participation from representatives involved in previous studies or programmes. An International Advisory Group has been established which includes individuals from B3 (New Zealand Expats Programme); APGA (US SPN); the French National Institute for Agricultural Research (INRA) and the Istituto per la Protezione Sostenibile delle Piante, Italy (PRATIQUE and ISEFOR). The Advisory Group provides guidance, advice and feedback to the project in order to ensure a truly global network, with individuals also championing the project within their respective countries. With that in mind, the Group also includes representatives from the Department of Plant Protection (FCA/UNESP) – Campus de Botucatu, Brazil; the South African National Biodiversity Institute (SANBI) and Centre for Invasion Biology (CIB), South Africa and the Royal Botanic Gardens, Kew, UK. Consequently individuals are located across five continents.

The main aim for the project now is to create a sustainable and viable network which will continue past the initial funding period which ends in April 2016. Championed by BGCI, it is hoped the IPSN will become an invaluable tool for both botanic gardens and arboreta wishing to increase their capacity and capability in this area. It will also help NPPOs in the identification and creation of appropriate PRAs.

To find out more about IPSN please visit www.plantsentinel.org

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